

Loop Calculations and OZI Rule

V. E. MARKUSHIN

Paul Scherrer Institute, CH-5232 Villigen, Switzerland

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Abstract

The role of two step mechanisms in the OZI rule violation in $N\bar{N}$ annihilation at low energies is reviewed. The full calculation of two-meson doorway mechanisms shows that the off-mass-shell contributions are important. Moreover, for the $\phi\pi^0$ and $\phi\rho$ annihilation channels three-meson doorway contributions are non-negligible and improve agreement with the data. A significant enhancement of ϕ production is found in the resonant rescattering mechanisms $\bar{p}p \rightarrow \pi^+\pi^-K\bar{K} \rightarrow \pi^+\pi^-\phi$ and $\bar{p}p \rightarrow \eta K\bar{K} \rightarrow \eta\phi$.

1 Introduction

The ϕ production in low energy $p\bar{p}$ annihilation is expected to be suppressed on the tree level according to the Okubo-Zweig-Iizuka (OZI) rule [1–3] because the ϕ meson is nearly a pure $s\bar{s}$ state. The ϕ production via $\phi\omega$ mixing (Fig.1a) is proportional to a small deviation of the vector octet mixing angle θ_V from the ideal one θ_i ($\omega_{\phi\omega} = \sin(\theta_V - \theta_i) \approx 0.065$) [4]. The corresponding amplitude T^{OZI} determines the expected scale of ϕ production. The reactions where this level is significantly exceeded (OZI rule violation) are of big interest for the studies of annihilation mechanisms and nucleon structure.

The experiments performed at LEAR (see [5–15] and references therein) have demonstrated, in agreement with earlier findings [16], that the OZI rule is strongly violated in several channels in $p\bar{p}$ annihilation at low energy. To explain these results two different theoretical approaches have been used. One approach [17–25] is based on higher order processes beyond the tree level (rescattering mechanisms), the second one assumes that the nucleon

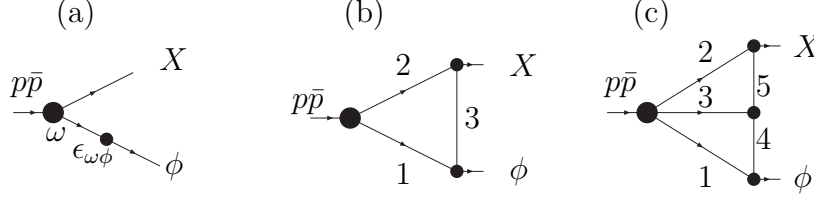


Figure 1: (a) The $\phi\omega$ mixing and the two-step processes for ϕ production: (a) two-meson doorway mechanism with intermediate state 1 2, (b) three-meson doorway mechanism with intermediate state 1 2 3.

has a significant intrinsic $s\bar{s}$ component [26, 27]. This paper, supplementing the earlier reviews [28–32], focuses on recent studies of the rescattering mechanisms in $p\bar{p}$ annihilation.

2 Two-step mechanisms

Two-step processes with ordinary hadrons in intermediate states are known to be a potential source of the OZI-rule breaking (see [33, 34]). The simplest two-step process in $p\bar{p}$ annihilation is the two-meson doorway mechanism shown in Fig.1b. Its role has been studied for various final states containing ϕ mesons [17–25]. In the $\phi\pi$ and $\phi\phi$ channels presenting the most dramatic hadronic violation of the OZI rule, two-step mechanisms predict cross sections comparable with the experimental data. The full calculation of two-meson doorway mechanisms [24, 35] shows that off-mass-shell contributions are of similar size as the unitarity approximation. The contributions from different intermediate states in the reaction $p\bar{p} \rightarrow \phi\pi^0$ are shown in Table 1. A constructive interference between the two-meson doorway contributions from the $K\bar{K}^*$ and $\rho\rho$ intermediate states [24] is already sufficient to explain the measured branching ratio $BR(\phi\pi^0)$ [5, 9, 10, 14].

However, for a number of reactions, including $p\bar{p} \rightarrow \phi\rho$, $\phi\pi\pi$, $\phi\omega$, no significant contributions from the two-meson doorway mechanisms have been found [20]. Since the annihilation into two non-strange mesons is less probable than into three mesons, three mesons are natural candidates for intermediate states leading to sizeable OZI-rule violation. Three meson doorway mechanisms for the reactions $(p\bar{p})_{3S_1} \rightarrow \phi\pi^0, \phi\eta$ and $(p\bar{p})_{1S_0} \rightarrow \phi\rho, \phi\omega$ at rest have been considered in [35] using the unitarity approximation (only the absorptive part of the diagrams in Fig.1c was calculated). For the $\phi\pi$ and

Table 1: The contributions from $\phi\omega$ mixing, from two-meson doorway and from three-meson doorway mechanisms to amplitude T and branching ratio BR for the reactions $(p\bar{p})_{3S_1} \rightarrow \phi\pi^0$ and $(p\bar{p})_{1S_0} \rightarrow \phi\rho^0$ at rest [24,35]. The intermediate states and the mesons exchanged are indicated according to Figs.1b,c. The amplitude T^{OZI} corresponds to $\phi\omega$ mixing with a point-like $p\bar{p} \rightarrow \phi X$ vertex; the effect of a dipole form factor in the annihilation vertex with cut-off parameter Λ is shown for the $\phi\rho$ case.

reaction	mechanism	$ T/T^{\text{OZI}} $	$BR(\phi X) \cdot 10^4$
$p\bar{p} \rightarrow \phi\pi^0$	Fig.1a $\phi\omega$ mixing	1.	0.15
	Fig.1b $\rho\rho$ (π)	$0.6 - 2.6$	$0.05 - 1.0$
	$K\bar{K}^* + \bar{K}K^*$ (K)	$2.0 - 3.3$	$0.6 - 1.6$
	$K\bar{K}$ (K^*)	< 0.5	< 0.03
	$K^*\bar{K}^*$ (K)	< 0.7	< 0.08
	Fig.1c $\pi\rho\pi$ (ρ, ω)	~ 2.0	~ 0.6
	$\rho\pi\pi$ (π, ρ)	~ 1.2	~ 0.2
	experiment [5]	5.2	4.0 ± 0.8
	experiment [9, 10]	6.7	6.5 ± 0.6
	experiment [14]	7.2	7.6 ± 0.6
$p\bar{p} \rightarrow \phi\rho^0$	Fig.1a $\phi\omega$ mixing	1.	0.14
	$\Lambda = 0.4 \text{ GeV}$	1.8	0.47
	Fig.1b $\omega\rho$ (π)	< 0.6	< 0.05
	$K\bar{K}^* + \bar{K}K^*$ (K)	< 0.3	< 0.01
	Fig.1c $\pi\omega\pi + \pi\pi\omega$ (ρ, π)	~ 1.1	~ 0.17
	$\pi\pi\pi$ (ρ, π)	~ 0.6	~ 0.06
	experiment [5]	4.9	3.4 ± 1.0

$\phi\rho$ channels, three particle intermediate states were found to be important, as shown in Table 1.

For all the channels considered, a consistent explanation of large and small OZI-rule violations emerges. In particular, the contribution of the doorway mechanisms relative to tree level $\phi\omega$ mixing is largest in the $\phi\pi^0$ channel where the most dramatic OZI rule violation in hadronic channels is observed. As required, the relative strength of the doorway mechanisms is smaller in channels with less dramatic breaking of the OZI rule. Furthermore, a consistency check was done by calculating the two-step mechanisms for annihilation into nonstrange mesons; the rescattering terms were found to be smaller than the tree-level terms strengthening the case for the consistency of the rescattering expansion [35].

While the rescattering mechanisms considered can explain the discussed OZI-rule violating reactions, exact predictions are often hindered by the lack of independent information about the relative phases of the competing contributions from different intermediate states. Lipkin cancellations [33, 34] seem to be unlikely in $p\bar{p}$ annihilation because the standard arguments based on the symmetry of intermediate states (like in the case of the vector meson octet mixing) do not apply. As an example where interference effects are important, we recall that the OZI rule violation in the $p\bar{p} \rightarrow \phi\gamma$ at rest finds its natural explanation in the framework of the vector meson dominance where a constructive interference between the intermediate states $\phi\omega$ and $\phi\rho$ is required, contrary to the case of annihilation into $\omega\gamma$ channel where the interference between the $\omega\omega$ and $\omega\rho$ is destructive (see discussion in [31] and references therein).

3 Resonant rescattering mechanism

A further type of rescattering mechanisms proceeding via resonant final state interaction in the $K\bar{K}$ was suggested recently in [36] where the reaction $p\bar{p} \rightarrow \phi\pi\pi$ was studied in detail. The total annihilation amplitude T has the

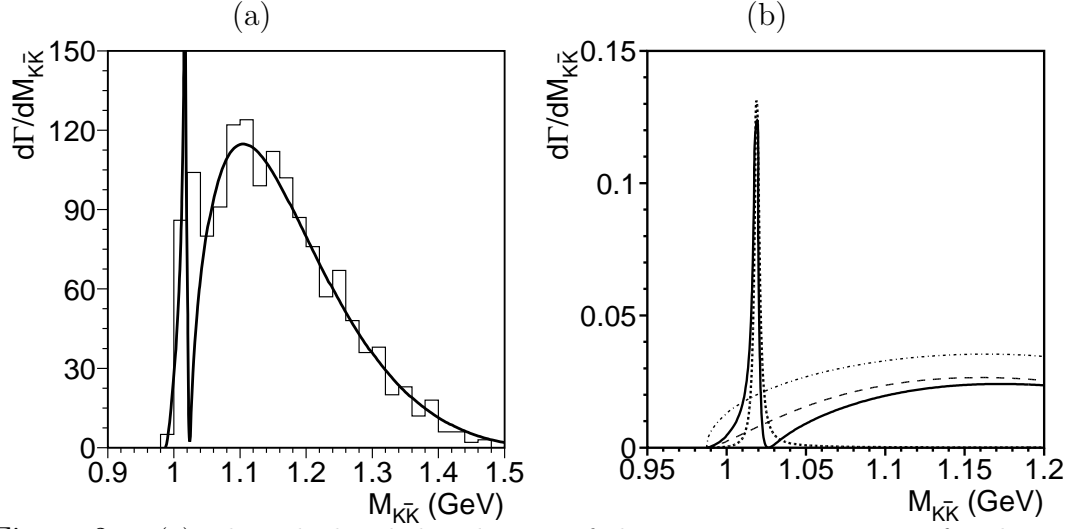


Figure 2: (a) The calculated distribution of the invariant mass $m_{K\bar{K}}$ for the reaction $\bar{p}p(^3S_1) \rightarrow K\bar{K}\pi^+\pi^-$ for $\beta = 2$ in comparison with the experimental data [37]. (b) The calculated distribution of the invariant mass $m_{K\bar{K}}$ for the reaction $\bar{p}p \rightarrow K\bar{K}\eta$ for $\beta = 4$. The full result is shown by the solid line, the pure resonance term by the dotted line, the plane wave approximation by the dashed line, and the phase space distribution by the dashed-dotted line, respectively.

form:

$$T = \begin{array}{c} \begin{array}{c} \pi^+ \\ \pi^- \\ K \\ \bar{K} \end{array} \\ \begin{array}{c} \nearrow \\ \nearrow \\ \searrow \\ \searrow \end{array} \\ p\bar{p} \rightarrow \bullet \end{array} + \begin{array}{c} \begin{array}{c} \pi^+ \\ \pi^- \\ K \\ \bar{K} \end{array} \\ \begin{array}{c} \nearrow \\ \nearrow \\ \searrow \\ \searrow \end{array} \\ p\bar{p} \rightarrow \bullet \end{array} \begin{array}{c} \begin{array}{c} \bar{K} \\ \phi \\ K \\ \bar{K} \end{array} \\ \begin{array}{c} \nearrow \\ \nearrow \\ \searrow \\ \searrow \end{array} \end{array} = g_a A(M_{K\bar{K}}) \quad (1)$$

where g_a is the annihilation vertex in the plane wave approximation and $A(s_{K\bar{K}})$ is the enhancement factor resulting from the final state interaction in the $K\bar{K}$ system with the invariant mass $M_{K\bar{K}}$:

$$A(s_{K\bar{K}}) = \frac{M_{K\bar{K}}^2 - m_\phi^2 - m_\phi \beta \Gamma_\phi}{M_{K\bar{K}}^2 - m_\phi^2 + i m_\phi \Gamma_\phi} \quad (2)$$

Here m_ϕ and Γ_ϕ are the mass and width of the ϕ meson and β is the ratio of the real to imaginary part of the $K\bar{K}$ loop in the second (rescattering) diagram in Eq.(1). Note that the absorptive part of the rescattering amplitude, which corresponds to K and \bar{K} on their mass shell (the unitarity approximation), can be expressed through the corresponding vertex functions in the physical region and is therefore well constrained by experimental data. Thus the model has only one parameter, β , which depends on the loop regularization. As shown in [36], the off-shell contributions are important for typical values $\beta > 2$.

The calculated distribution of the invariant mass $m_{K\bar{K}}$ for the reaction $p\bar{p} \rightarrow K\bar{K}\pi^+\pi^-$ is shown in Fig.2a in comparison with the experimental data. The predicted branching ratio $BR(p\bar{p}(^3S_1) \rightarrow \phi\pi^+\pi^-) \geq 3 \cdot 10^{-4}$ for $\beta \geq 2$ agrees well with the OBELIX $BR((p\bar{p})_{liq} \rightarrow \phi\pi^+\pi^-) = 3.5(4) \cdot 10^{-4}$ [12], the ASTERIX analysis $BR(p\bar{p}(S) \rightarrow \phi\pi^+\pi^-) = 4.7(11) \cdot 10^{-4}$ [5] as well as with the values obtained from the old bubble chamber measurements $BR(p\bar{p}(S) \rightarrow \phi\pi^+\pi^-) = 5.4(9) \cdot 10^{-4}$ [37] (see [36] for details) and $BR(p\bar{p}(S) \rightarrow \phi\pi^+\pi^-) = 4.6(9) \cdot 10^{-4}$ [38].

The theoretical prediction for the invariant mass $m_{K\bar{K}}$ in the reaction $p\bar{p}(^3S_1) \rightarrow K\bar{K}\eta$ is shown for $\beta = 4$ in Fig.2b. The relative strength of the ϕ peak depends sensitively on the corresponding ratio β which reflects the properties of the $p\bar{p} \rightarrow K\bar{K}\eta$ amplitude. Its dependence on the initial $p\bar{p}$ state can be a reason for the strong difference between the branching ratios $BR(p\bar{p}(L) \rightarrow \phi\eta)$ for the S and P -states seen in recent OBELIX data [13].

The interference of the resonant term with the nonresonant background is essential for the correct analytical properties of the total amplitude and leads to a characteristic peak-dip structure of the invariant $K\bar{K}$ mass distribution, see Fig.2. Another interesting feature of the resonant rescattering mechanism is that the ϕ production decreases with increasing beam energy as the fraction of phase space favorable for resonance formation gets smaller. This is in agreement with the general trend observed for the OZI rule violation in nucleon-antinucleon annihilation.

4 Conclusion

Systematic calculations of the OZI rule violation due to two-step mechanisms in the reactions $p\bar{p} \rightarrow \phi\pi^0, \phi\rho^0, \phi\pi^+\pi^-, \phi\eta$ at rest are now available. In the $\phi\pi^0$ channel, the two-meson doorway mechanisms with the $K\bar{K}^*$ and $\rho\rho$ intermediate states are sufficient, assuming constructive interference, to explain the observed dramatic violation of the OZI rule. In this case a sizeable contribution is also expected from the three-meson doorway mechanisms. Three-meson doorway mechanisms are also found to be important in the $\phi\rho$ channel which previously could not be explained by the two-meson doorway mechanisms alone. The characteristic scale of the doorway mechanisms is well determined by the experimental information. The contributions from the doorway mechanisms are large for the channels with dramatic violation of the OZI rule and small for the channels with moderate violation. Therefore, a self-consistent picture of ϕ production in $p\bar{p}$ annihilation emerges.

A resonant $K\bar{K}$ rescattering mechanism (final state interaction) is important for ϕ production in the $p\bar{p}$ annihilation at low energy. The contribution of this mechanism to the $\phi\pi\pi$ channel agrees with experiment and is a good candidate for the explanation of the annihilation into the $\phi\eta$ channel as well. The ϕ production via the resonant rescattering mechanism decreases with increasing total energy in agreement with the observed general trend.

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